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CAPTURE-EFFECT AND SIDEBAND-REFERENCE GLIDE-SLOPE PERFORMANCE IN THE PRESENCE OF DEEP SNOW

1977-1978

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FINAL REPORT

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16. Abstract

Results of capture-effect and sideband-reference glide-slope system response to up to 21 inches of snow in the reflecting zone are presented. These results show that the capture-effect path angle increases at 0.08° per foot of snow, and the sideband-reference path angle increases at 0.30° per foot of snow. No significant degradation in path clearance or width was observed. Data was also collected on near-field and integral monitors performance, and static path angle values at runway threshold.

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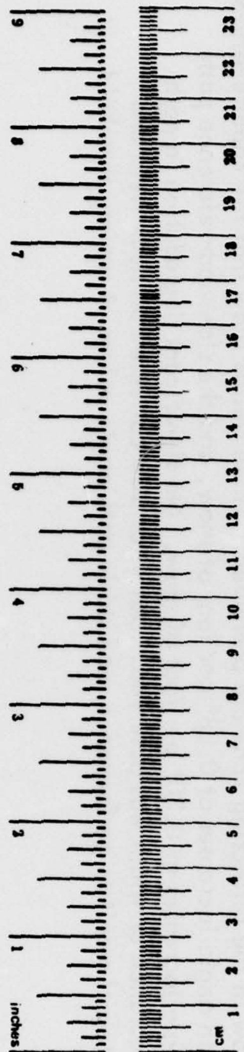
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

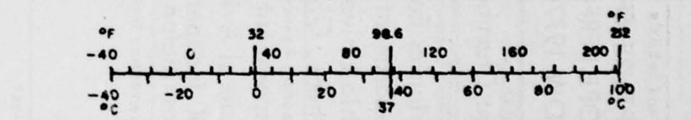
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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I. CONCLUSIONS

Based on two years of data collection on the experimental Sideband-Reference Glide-Slope System at Houghton, Michigan, and one year of data collection on the Capture-Effect System, the following conclusions are made:

1. The capture-effect system was shown to experience a path angle increase of 0.08 degree per foot of snow in the reflecting zone considering depths up to 21 inches.

2. Path angle for the Sideband-Reference System increased at the rate of 0.21 degree per foot of snow during the 1976-77 snow season, and 0.30 degree per foot of snow during the 1977-78 snow season.

3. The course width for the Sideband-Reference System was shown to decrease at the rate of 0.07 degree per foot of snow for both snow seasons and no change in course width was observed for the capture effect system.

4. No deterioration of clearance below path was observed for either system.

5. Again, evidence shows that no significant lowering of the glide-slope angle was seen with an increase in snow depth.

6. Observed far-field behavior for both systems is consistent with theory, and revealed no anomalous behavior.

7. Far-field path characteristics are not accurately predicted by near-field monitors in the presence of deep snow.

8. The path structure near runway threshold was observed to be slightly rougher with deep snow in the reflecting zone than with no snow in the reflecting zone.

9. A comparison of flight measurements and static measurements made at runway threshold with a Clark Tower indicates that the static measurements do not necessarily predict far-field path behavior principally because of the different ground plane conditions affecting the two regions of measurements. Snow accumulation along the runway due to plowing will affect the elevations of the path over the threshold and the structure of the paths approaching the threshold.

10. An installation of VASI's elevated 48 inches above the ground did not significantly affect glide-slope operation.

II. INTRODUCTION

This report presents the latest results in a continuing study of image-type glide-slope systems operating in a deep-snow environment. The primary need for such a study arises from the fact that near-field monitors, which are presently used to sense out-of-tolerance conditions, are typically overly-sensitive to snow accumulation thus producing unnecessary shutdowns of facilities even though acceptable paths exist in the far field. Clearly, such operations potentially deprive the user of navigation information at times when it is needed most. High-performance jet aircraft in particular require accurate guidance information even in the best of weather conditions; removal of a glide slope from service during poor weather has been documented to be a serious compromise in safety and should be allowed only when absolutely justified.

Prior work on null-reference glide-slope systems has been performed and reported by Ohio University. [1,2,3,4,5] The results obtained in those investigations are consistent with theory, showing a 0.10° increase in path angle with every foot of snow accumulation. The work reported here is concerned with the performance of capture-effect (CE) and sideband-reference (SBR) systems operating in the presence of deep snow; as with the null-reference study, the results presented here are also consistent with theory, revealing no anomalous behavior.

The current work was performed at the Houghton County Memorial Airport in Houghton, Michigan, using an experimental glide-slope facility serving Runway 25. Because this facility is not commissioned, snow is not removed from the reflecting zone, thus allowing a complete study of snow effects to be made. The work was done principally by Michigan Technological University (MTU) as subcontractor to Ohio University. MTU maintained the experimental facility and performed routine ground and airborne measurements. OU provided administrative and technical support and in adddition periodically flight checked the facility to verify MTU measurements. It should be noted that close agreement between MTU and OU airborne measurements was realized in every case.

Complete integral monitors (path and width) and conventional near-field monitors were employed for both systems for the duration of the study. As expected, the near-field monitors, except for the SBR 270° monitor, were overly sensitive to snow effects*, indicating alarm condition well before degradation in the far-field path was observed. Additionally, at times the integral monitors remained in-tolerance even though the far-field path had exceeded tolerances as a result of snow effects. However, it became evident that predictions concerning far-field path angle can accurately be made given snow depth and integral monitor response. Conceivably, such information could be used to keep a facility on the air at times when near-field monitors indicate alarm conditions.

* A counterpoise was not used for SBR near-field monitoring.

This study originally was to have been performed during the 1976-1977 snow season; however, because some of the capture-effect system components were not available at first, the work was extended over a two-year period. Data on the SBR system was collected during the first year, with the combined CE, SBR system operating during the 1977-1978 season. The first year's SBR data collection was not as extensive as the second year, and the monitoring was not established prior to ground plane snow cover. Consequently, the results on the SBR system presented here come primarily from the second year work with snow depths as great as 21 inches, although there is general agreement with the data collected during the first year effort.

III. TEST FACILITY

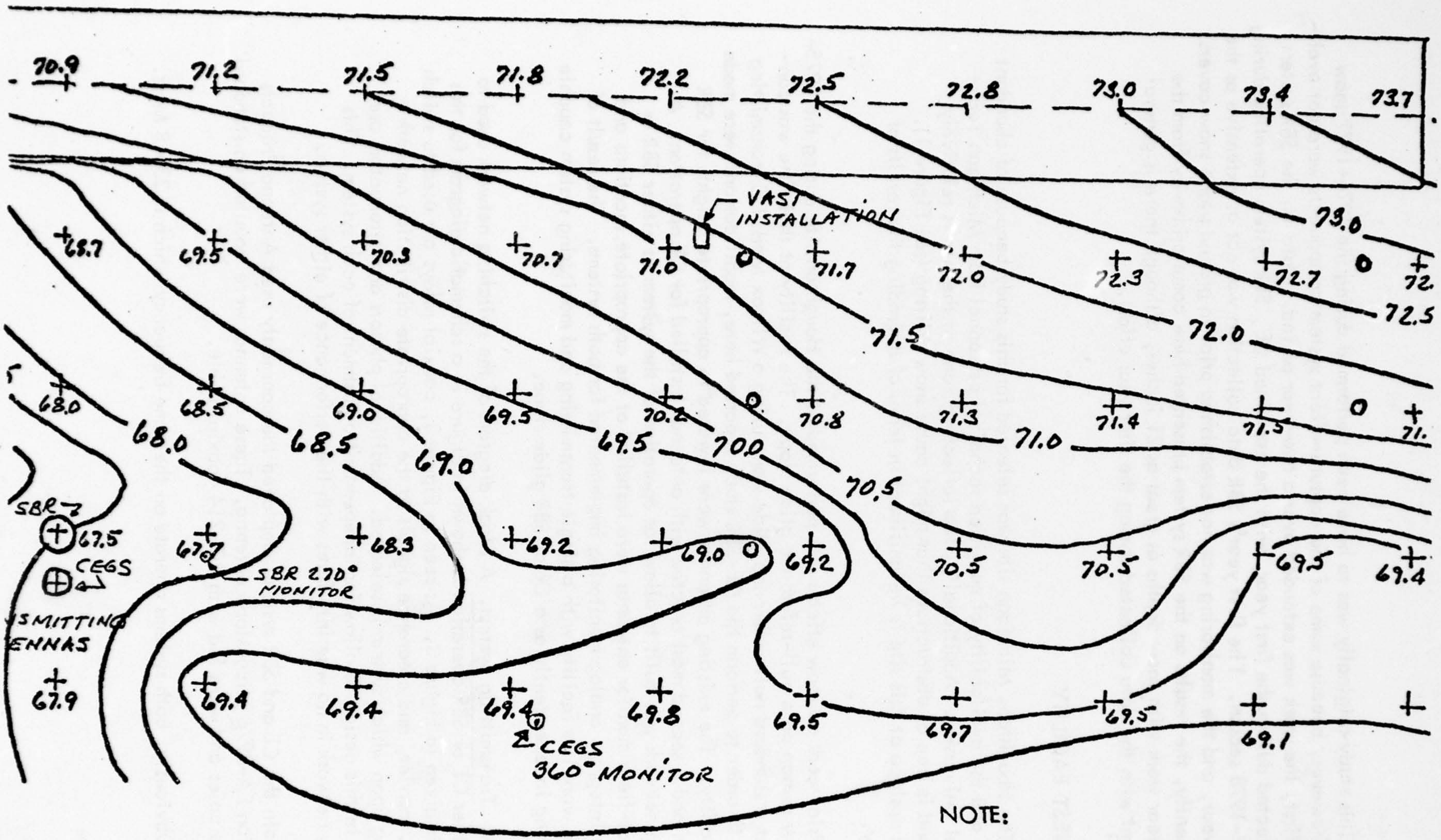
The Houghton, Michigan site was selected for this study because of abundant snowfall and the availability of qualified technical personnel from Michigan Technological University. Additionally, the reflecting zone at the site is relatively smooth and is free of obstructions that might cause snow drifting (see Figure 1). The mild upslope at this site is insignificant in terms of degrading the results of this study.

Prior work on snow effects was performed at the Houghton site during the 1975-1976 snow season on a null-reference glide slope. The facility at that time was configured as a standard null-reference glide slope using a Wilcox Mark I C transmitting system. In order to perform the CE-SBR study reported here, modifications were made to the facility. The existing antennas were lowered to appropriate heights for SBR operation and a second mast erected with antennas installed for CE operation. A switching network was built to allow for operation of the system as either SBR or CE. Near-field monitor antennas were installed at the appropriate locations and complete integral, analog monitoring implemented for both systems. The result of the above work is a facility with a single transmitting and monitoring system capable of operating independently as a CE or SBR glide slope.

A. <u>Transmitting System.</u> A block diagram of the switching network used to select either CE or SBR operation is shown in Figure 2; a schematic diagram for this network is given in Figure 3. As seen in Figure 3, coaxial relays are used to switch sideband, carrier, and clearance signals to the appropriate distribution network depending upon which system is selected. Additional phasors and attenuators are included in this design to allow for independent adjustment of each system. This switching network in no way interferes with the performance of either system.

Both the CE and SBR systems employed the commonly used Antenna Products Corporation FA-8976 glide-slope antenna. These antennas were mounted on standard telephone poles and were fed with RG-214 coaxial cable.

Obviously, both systems operate on the same frequency which is 330.8 MHz.



NOTE:

Snow Depth Stakes Represented by O
Add 1000' to indicate elevations to obtain actual elevation MSL

Figure 1. Contour Map of the Experimental Glide-Slope Reflection Zone on Runway 25 at the Houghton County Memorial Airport.

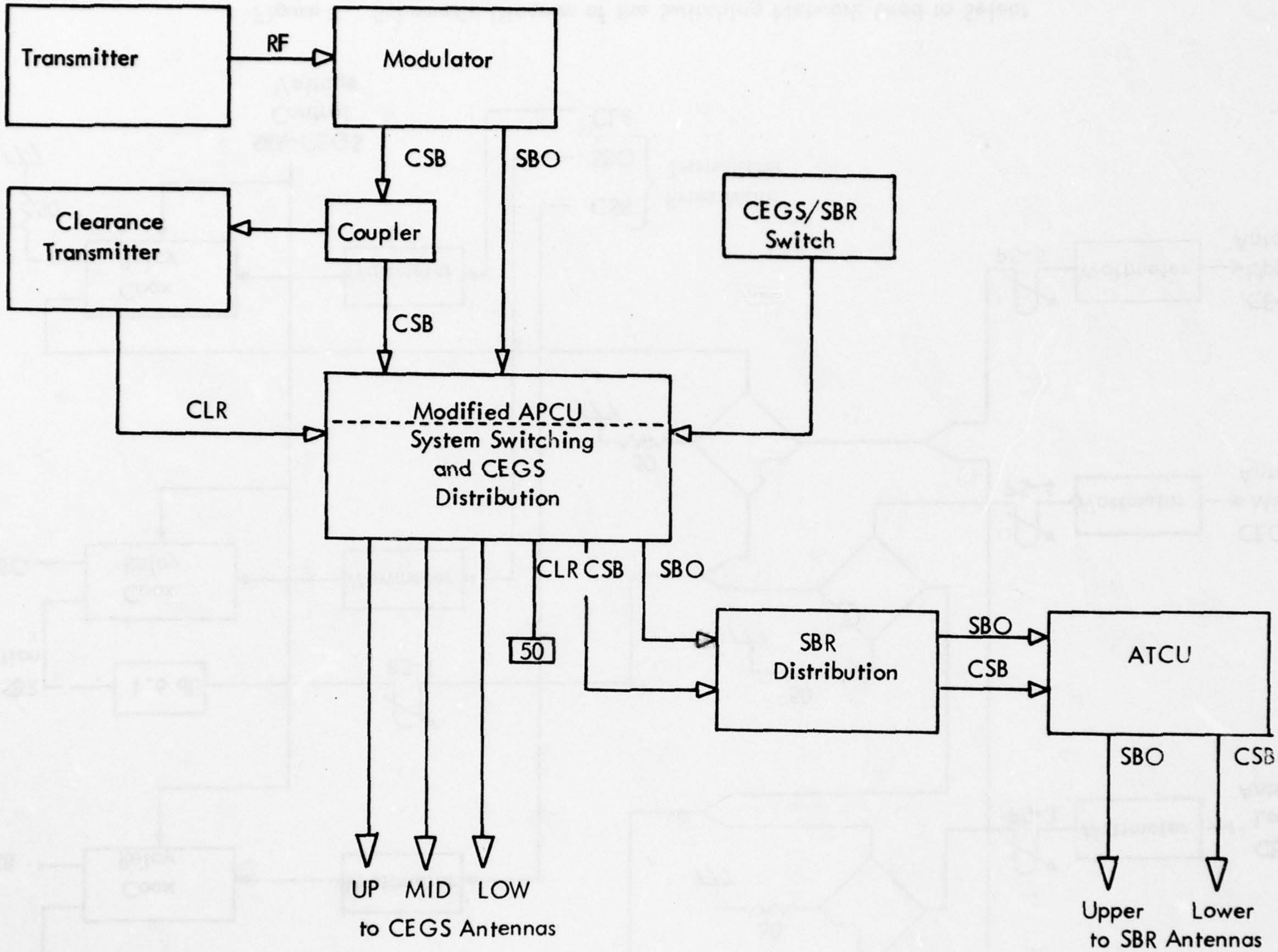


Figure 2. Block Diagram of the Switching Network Used to Select Sideband-Reference or Capture-Effect Operation.

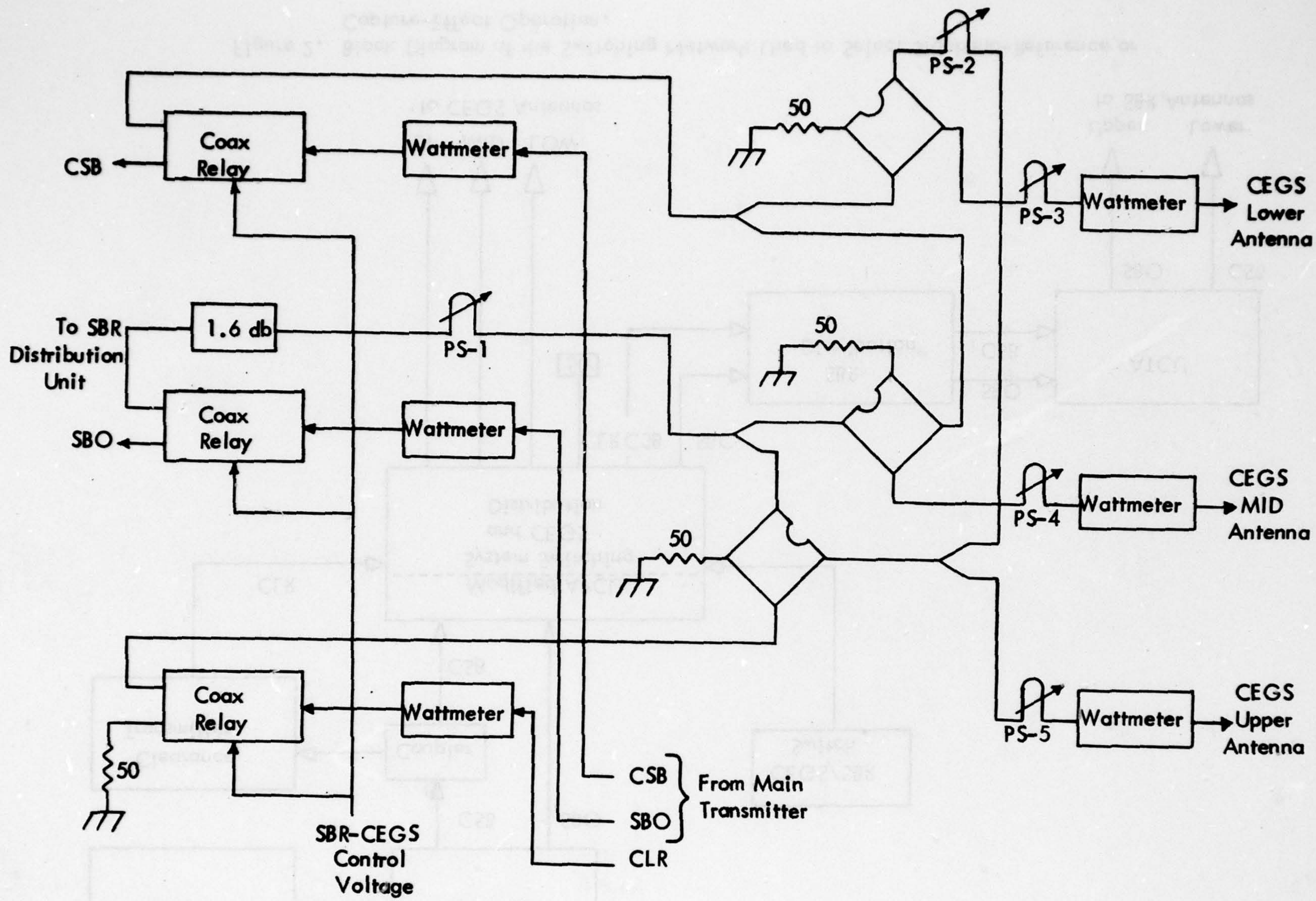


Figure 3. Schematic Diagram of the Switching Network Used to Select Sideband-Reference or Capture-Effect Operation.

B. Monitoring. Signals from either the CE or SBR monitor detectors are switched into the Mark I C monitor panel by the network shown in Figure 4. As shown in Figure 4, SBR or CE, and integral or field inputs can be selected. This switching network does not affect monitor operation.

Near-field monitor antenna locations are shown in Figure 5, indicating the CE 360° proximity point and the SBR 270° and 360° proximity points. These monitor locations were determined by methods described in the FAA Glide-Slope Installation Manual (FAA 6750.6A).

Path and width analog integral monitoring was implemented on both systems. An integral monitor network obtained from Wilcox was used on the SBR, and the integral monitor network depicted in Figure 6 was used for the CE. The integral monitor network of Figure 6 was used for this application because conventional CE integral monitors provide width information only, and full integral, analog-type monitoring was considered essential for this study. The design for this integral monitor was taken from previous work at Ohio University.[6] A comparison of the width function of the integral monitor of Figure 6 with the width function of the conventional GRN-27 integral monitor reveals that both integral monitors derive width information in the same manner. The difference between the two is that the integral monitor of Figure 6 employs phasors and attenuators to achieve desired phase and amplitude relationships, while the GRN-27 integral monitor depends on cable length and pick-up probe position to control phase and amplitude.

Monitor performance and alarm limits were determined by airborne measurements made by Ohio University prior to any snowfall. Changes in path width and angle were introduced by changing sideband power and modulation balance, respectively; monitor response to these changes was generally linear and proved effective in predicting far-field performance in the absence of snow. Path alarm limits were set at 2.90° and 3.17° for CE, and 2.86° and 3.09° for SBR. Width alarm limits were set at 0.53° and 0.90° for CE, and 0.51° and 0.94° for SBR.

Monitor readings were routinely recorded during this study to verify system performance as well as to obtain more information on monitor stability. Standard deviations for the integral monitors at the Houghton site during the 1977-1978 snow season have been computed in terms of percent alarm and are given in Table 1.

There is little documentation available on integral monitor stability over an extended period of time, thus making it difficult to draw conclusions concerning monitor stability for this study. However, the variations in integral monitor response as given in Table 1 do intuitively appear to be excessively high.

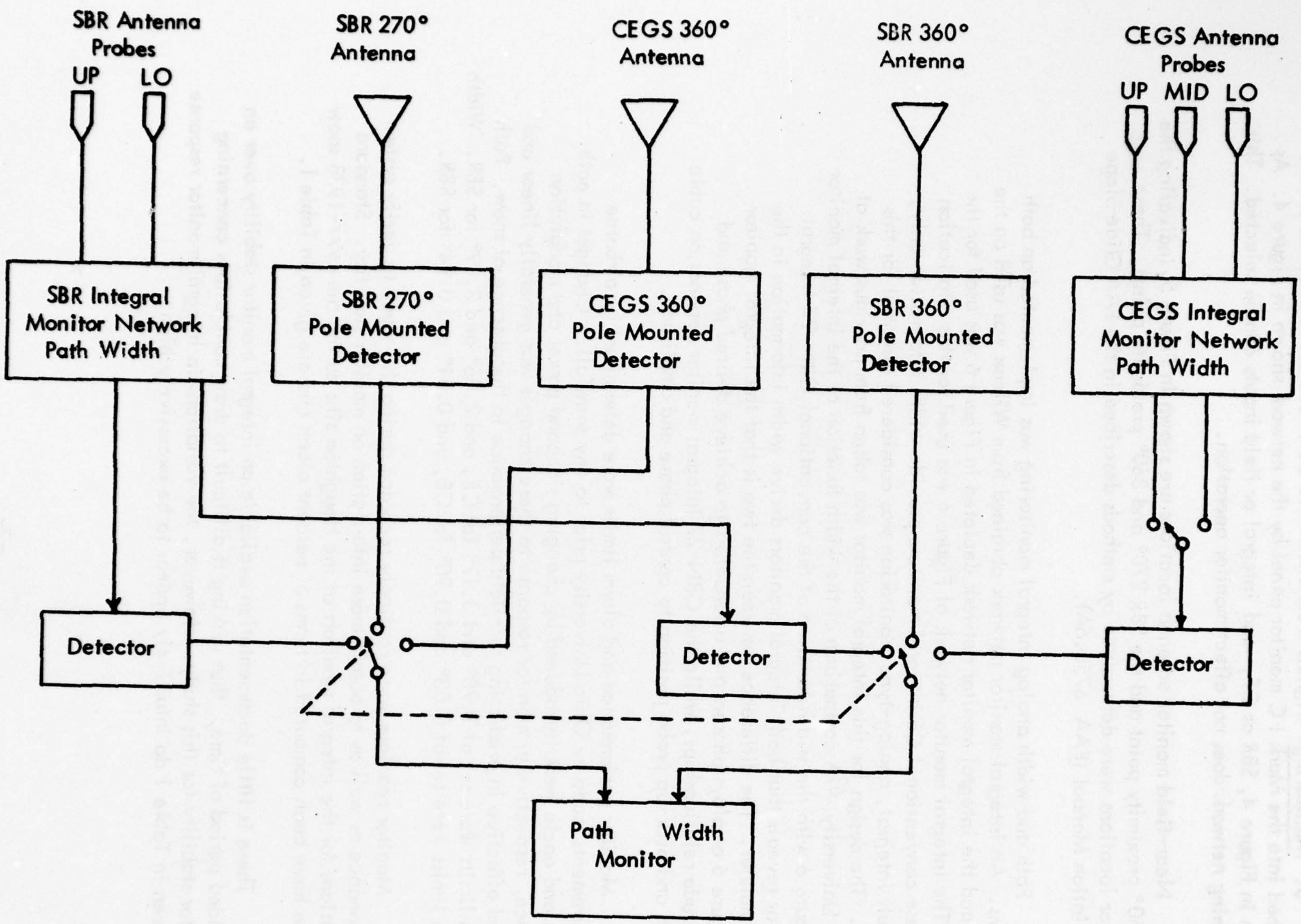


Figure 4. Switching Network to Select Integral or Near-Field, and Sideband-Reference or Capture-Effect Monitor Detector Inputs to the Monitor Panel.

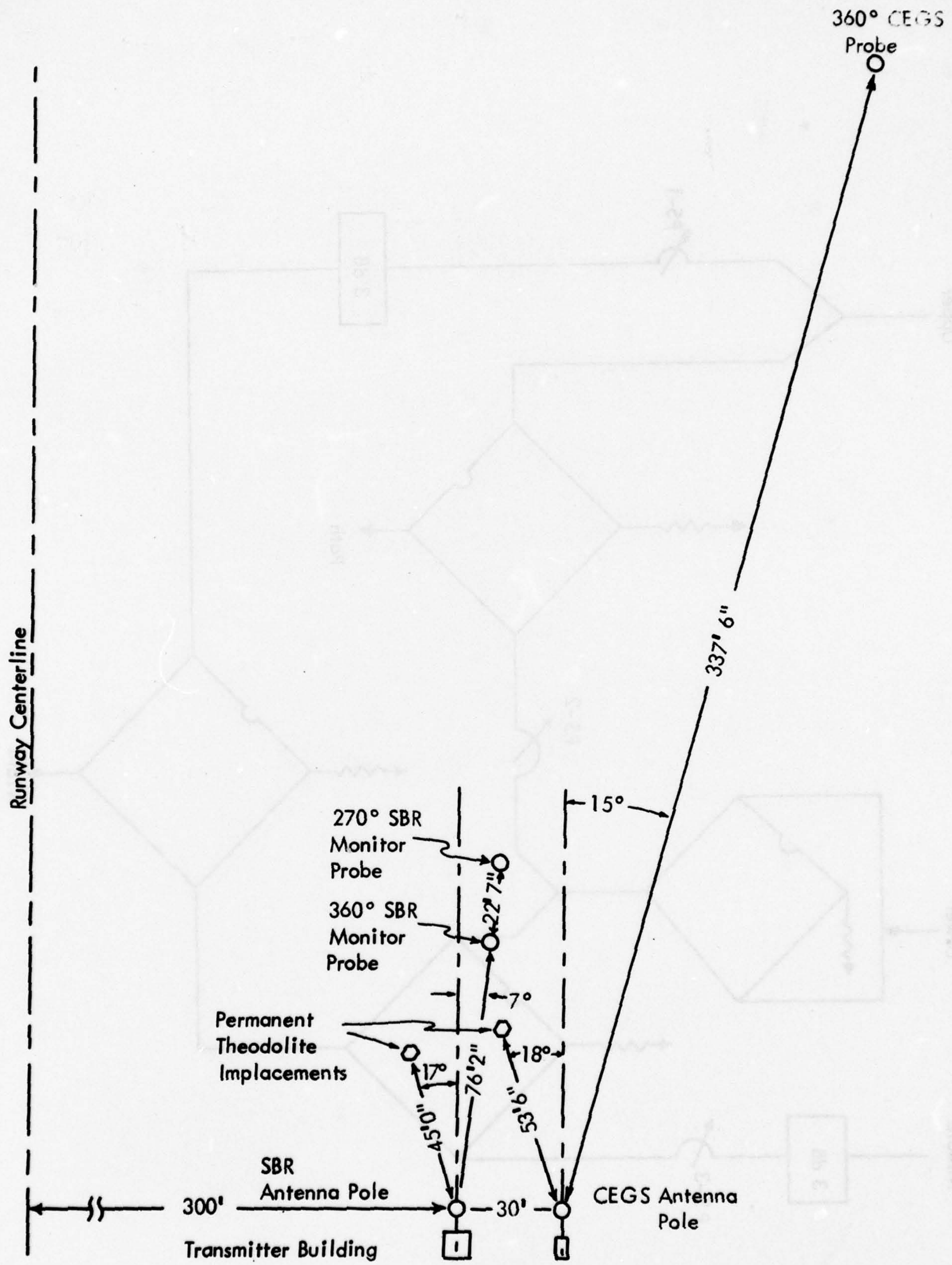


Figure 5. Map Showing Theodolite and Antenna Pole Implacements at the Experimental Glide Slope Facility.

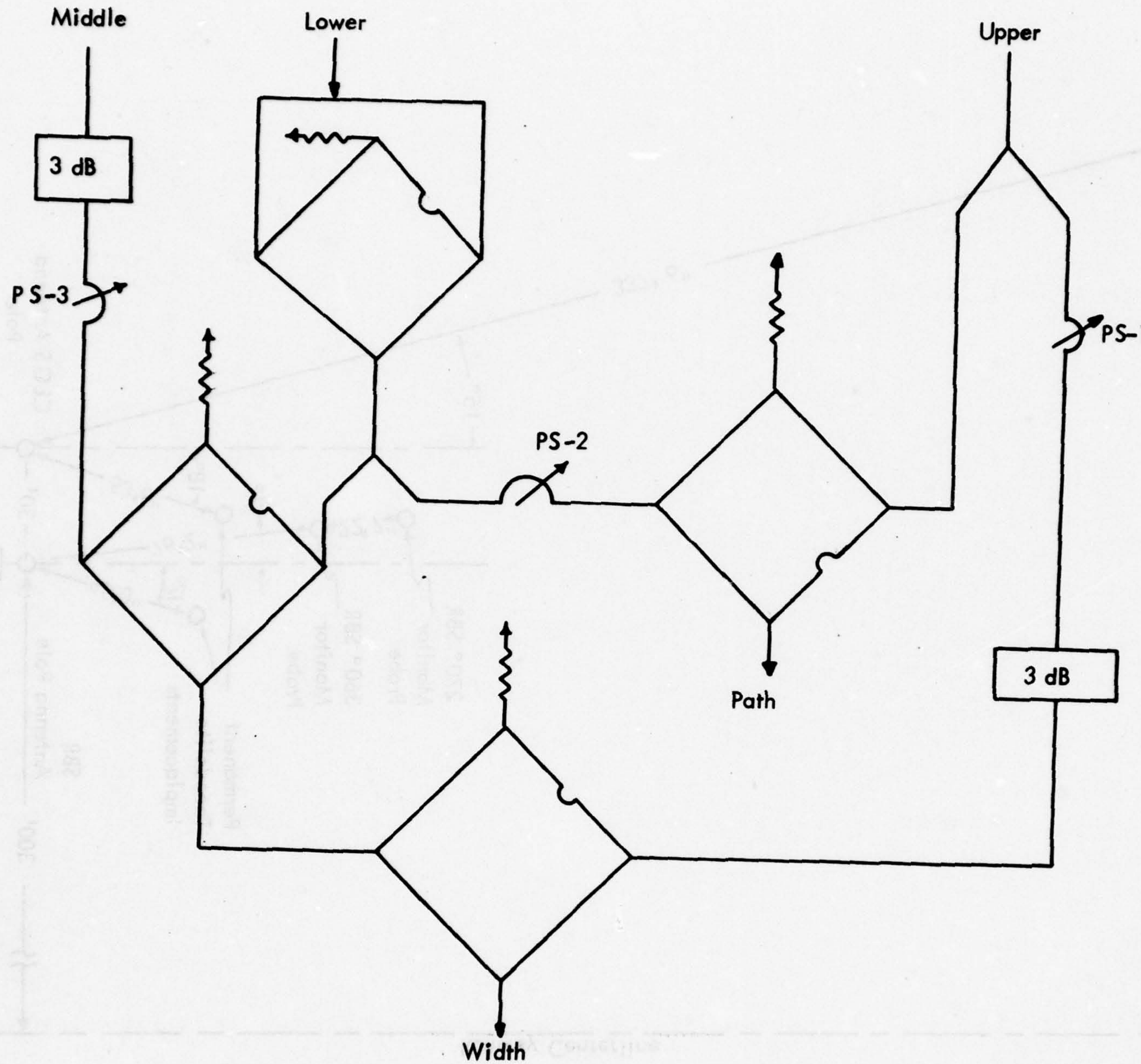


Figure 6. Capture-Effect Integral Monitor Network.

INTEGRAL MONITOR	STD. DEV. % ALARM
CE path	16
CE width	48
SBR path	50
SBR width	37

Table 1. Integral Monitor Stability Data.

At one point during this study, a shift in the CE integral width monitor occurred resulting in an alarm condition. Antenna currents were measured by induction probe and the system was flight checked (no additional snow had accumulated since the monitor shift occurred) in order to determine the cause of the monitor shift. No discernible change was measured in the transmitting system, indicating that the shift was caused solely by the monitor.

An important conclusion that can be drawn from the integral monitor data is that there were no substantial system changes other than snow in the reflecting zone to derogate the data quality. This conclusion is substantiated by baseline data which shows nearly the same path angle and width both before and after the 1977-1978 snow season.

IV. DATA COLLECTION

Thorough documentary data was collected on the Houghton facility before, during, and after the snow season. All transmitter voltages available on the built-in test equipment, sideband and carrier signal power, power delivered to each antenna, snow depth in the reflecting zone, and all monitor indications were recorded on a routine basis regardless of weather conditions.

The primary objective of this study, however, is to determine the impact of snow accumulations on the user. Accordingly, principal emphasis was placed on airborne measurements. All flight measurements were made in accordance with the United States Standard Flight Inspection Manual.

A. Flight Measurements. After the systems had been set up, extensive flight data were collected in the absence of snow to determine the repeatability with which glide-slope measurements could be made. These data represent the base from which the Michigan Technological University measurements must be referenced when assessing dispersion. This information concerning the size of basic measurement errors, permits a more judicious evaluation of the data collected in the presence of snow.

The majority of airborne measurements were taken by Michigan Technological University. These measurements were made in a light aircraft with a calibrated UGR-2 glide-slope receiver with an expanded CDI* scale. This airborne receiver was calibrated before the flight and then re-checked after the flight to determine if drift had occurred (typically, no drift had occurred). Flight measurements and calibration were both performed using the airborne receiver's battery-operated power supply, thus insuring that power fluctuations would not interfere with the data taking. A Boonton Model 232 Glide-Slope signal generator was used for calibration.

Glide path characteristics were determined by level pass and low-approach flight profiles. On the low approach, the aircraft flew on-path towards threshold and radioed the theodolite operator whenever exactly zero DDM was received. The angles measured by theodolite for these zero DDM indications were averaged to determine path angle. Level passes were flown at 1000 feet AGL along the centerline extended. The theodolite operator radioed elevation angle every tenth degree and the measured CDI corresponding to that angle recorded. A plot of CDI versus elevation angle was made from this measurement yielding path angle, width, and clearance information.

Permanent theodolite poles are installed at appropriate locations for both systems as shown in Figure 5. Marks corresponding to zero degree elevation angle from the theodolite have been placed on the monitor antenna poles for the purpose of theodolite calibration. Consequently, theodolite errors were essentially eliminated.

Ohio University flight measurements were made with the Mini-Lab data collection package [7] installed in a Model V-35A Beechcraft Bonanza. Calibration was accomplished using an IFR NAV401L signal generator. Telemetry for low-approach flights was provided by a Reaction Instrument Model 6050 telemetry transmitter. A Warren-Knight Model 84 theodolite was used by both Ohio University and Michigan Technological University.

B. Ground Measurements. Ground measurements were made at the runway threshold using the 60 foot telescoping Clark Tower and a calibrated portable ILS receiver (PIR). Elevation angle information for these measurements was provided by theodolite resulting in the determination of angle path and width at threshold.

V. GLIDE SLOPE DATA

A. Flight Measurement Results. Comprehensive flight measurement results for the 1977-1978 snow season are given in Figures 7 and 8 showing glide path

*Course Deviation Indicator calibrated in microamperes.

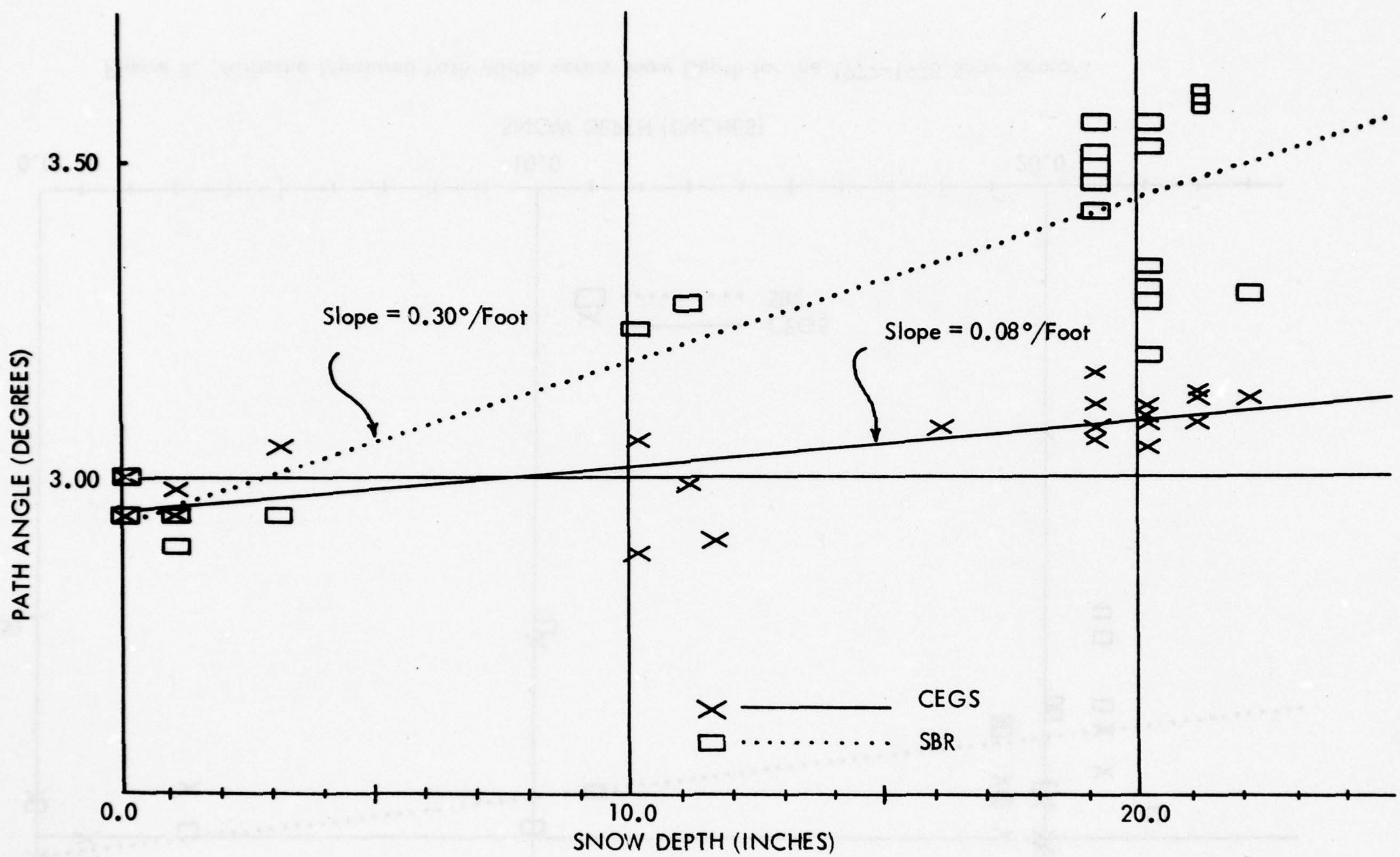


Figure 7. Airborne Measured Path Angle versus Snow Depth for the 1977-1978 Snow Season.

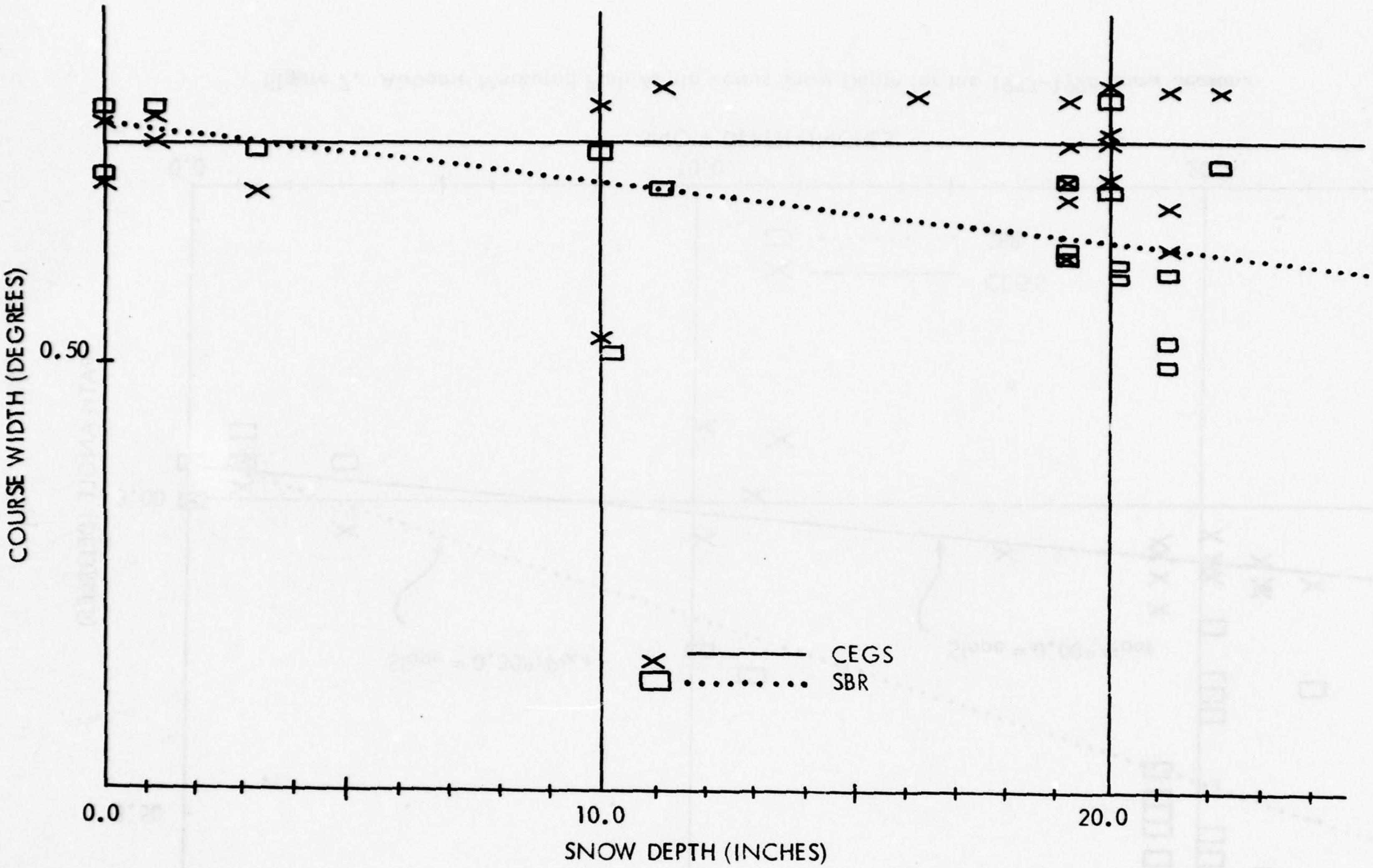


Figure 8. Airborne Measured Path Width versus Snow Depth for the 1977-1978 Snow Season.

angle and width versus snow depth for both the SBR and CE systems. The solid and dotted lines in these figures represent the least-mean-squared-error approximations to the measured data. The path angle/ snow depth and path width/ snow depth relationships are based on the slopes of these lines. These slopes show a 0.30 per foot of snow increase in path angle for the SBR, and 0.08° per foot of snow increase in path angle for the CE. Path width did not change with snow depth for the CE, and a narrowing of path width by 0.07° per foot of snow was observed for the SBR.

A significant dispersion of data points is evident in Figures 7 and 8. Similar dispersion is evident in the baseline data, indicating that measurement error, not snow effect, is responsible for this dispersion. Past work by Ohio University on glide-slope measurements indicates that such measurements can be made with much greater accuracy than is evident in Figure 7 and 8. Fortunately, because of the large number of data collected, the measurement error tends to wash out in the least-mean-squared-error approximation, revealing the general glide slope, far-field response to snow accumulation as indicated above.

There is a notable difference in the path-angle/snow-depth relationship for the SBR system between the 1976-1977 and 1977-1978 snow seasons. These values were measured to be 0.21° per foot of snow for the 1976-1977 snow season and 0.30° per foot during the 1977-1978 snow season. The reason for this difference is that substantially less data was collected during the 1976-1977 snow season causing measurement error to have a more pronounced effect on the least-mean-squared-error approximation to the measured data. Additionally, complete monitoring had not been set up prior to the 1976-1977 snow season and consequently there may have been undetected system changes resulting in changes in path characteristics. As mentioned in the Introduction, the 1976-1977 data collection effort was not intended to be an extensive study; accordingly, only general trends, and not specific values, should be considered as results for this first year's work.

Both systems were flight checked twice by Ohio University subsequent to system set-up and prior to the snow season; flight records from this documentation effort are presented in Figures 9 through 12. As can be seen in these figures, crossovers are generally linear and path structures are smooth. Clearly both systems were well within FAA tolerance limits prior to snow accumulation. The systems were also checked by Ohio University after 21 inches of snow had accumulated in the reflecting zone. These flight records again show linear crossovers, albeit at higher elevation angles, but reveal slightly rougher path structures near threshold (see Figures 13 and 14). This increased roughness in path structure, although still within tolerance limits, is felt to be a result of uneven snow on the sides of the runway caused by snow removal.

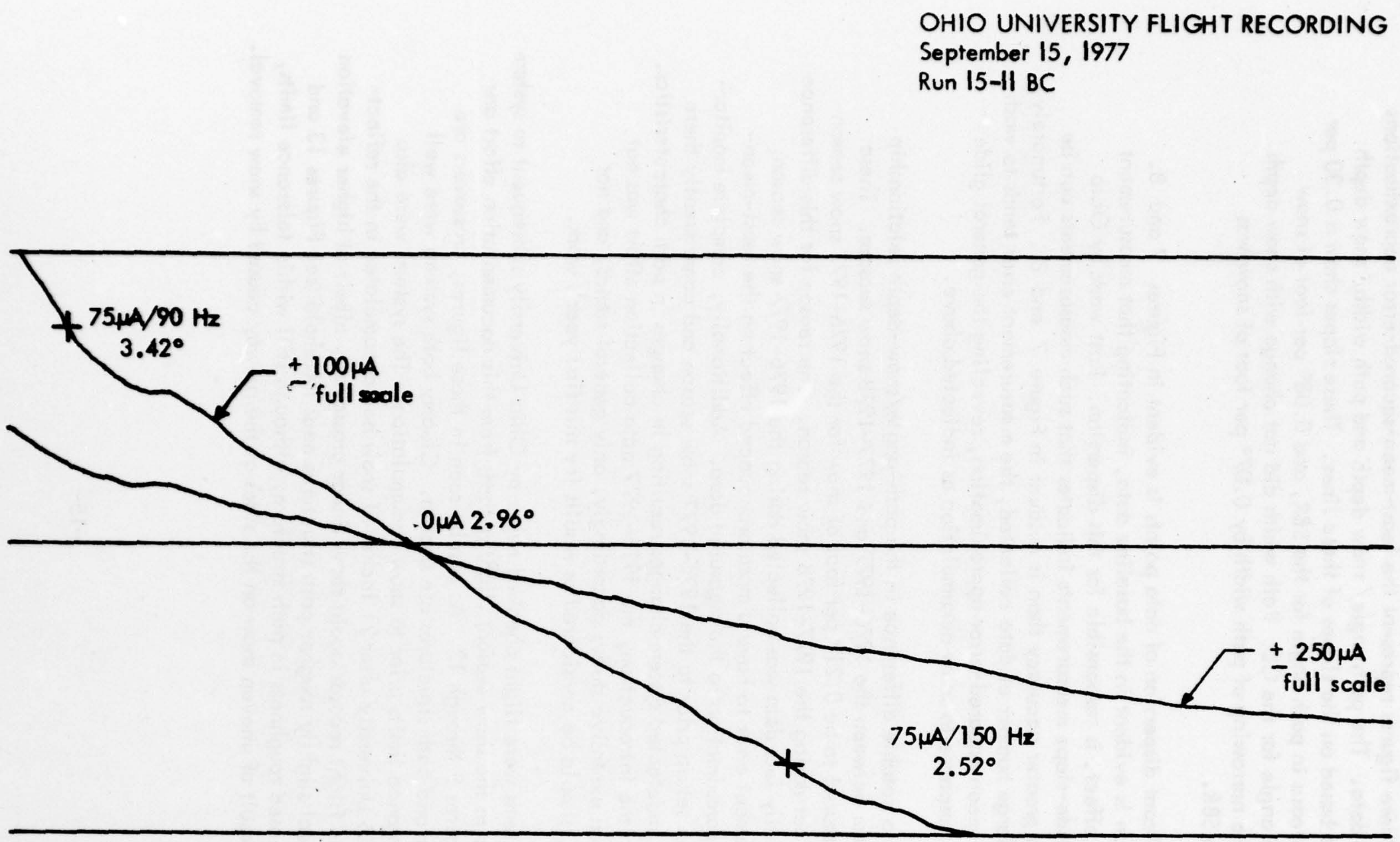


Figure 9. Course Deviation Indication versus Elevation Angle Observed During Level-Pass Flight With No Snow in the Reflecting Zone for the Sideband-Reference System.

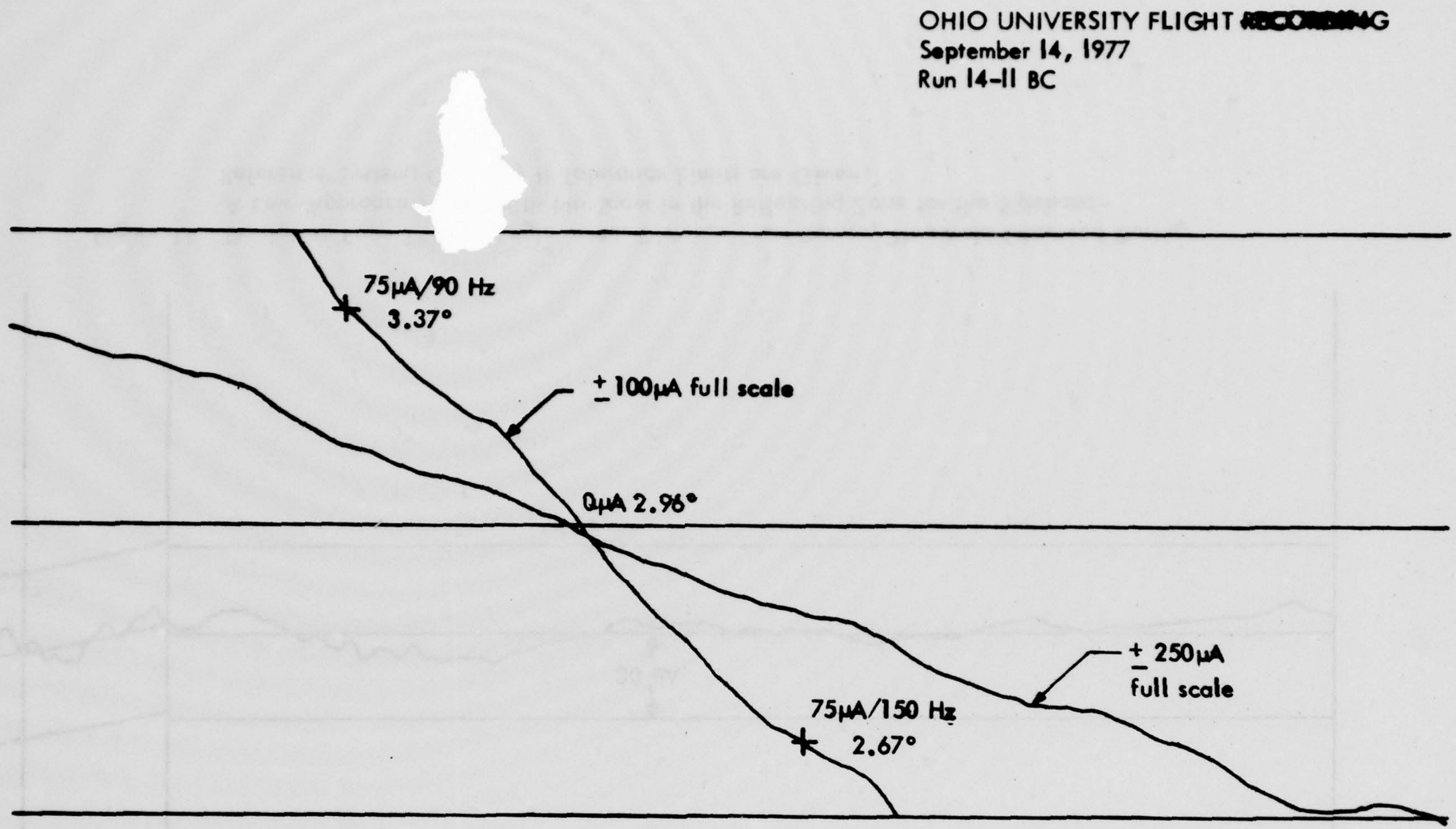


Figure 10. Course Deviation Indication versus Elevation Angle Observed During Level-Pass Flight With No Snow in the Reflecting Zone for the Capture-Effect System.

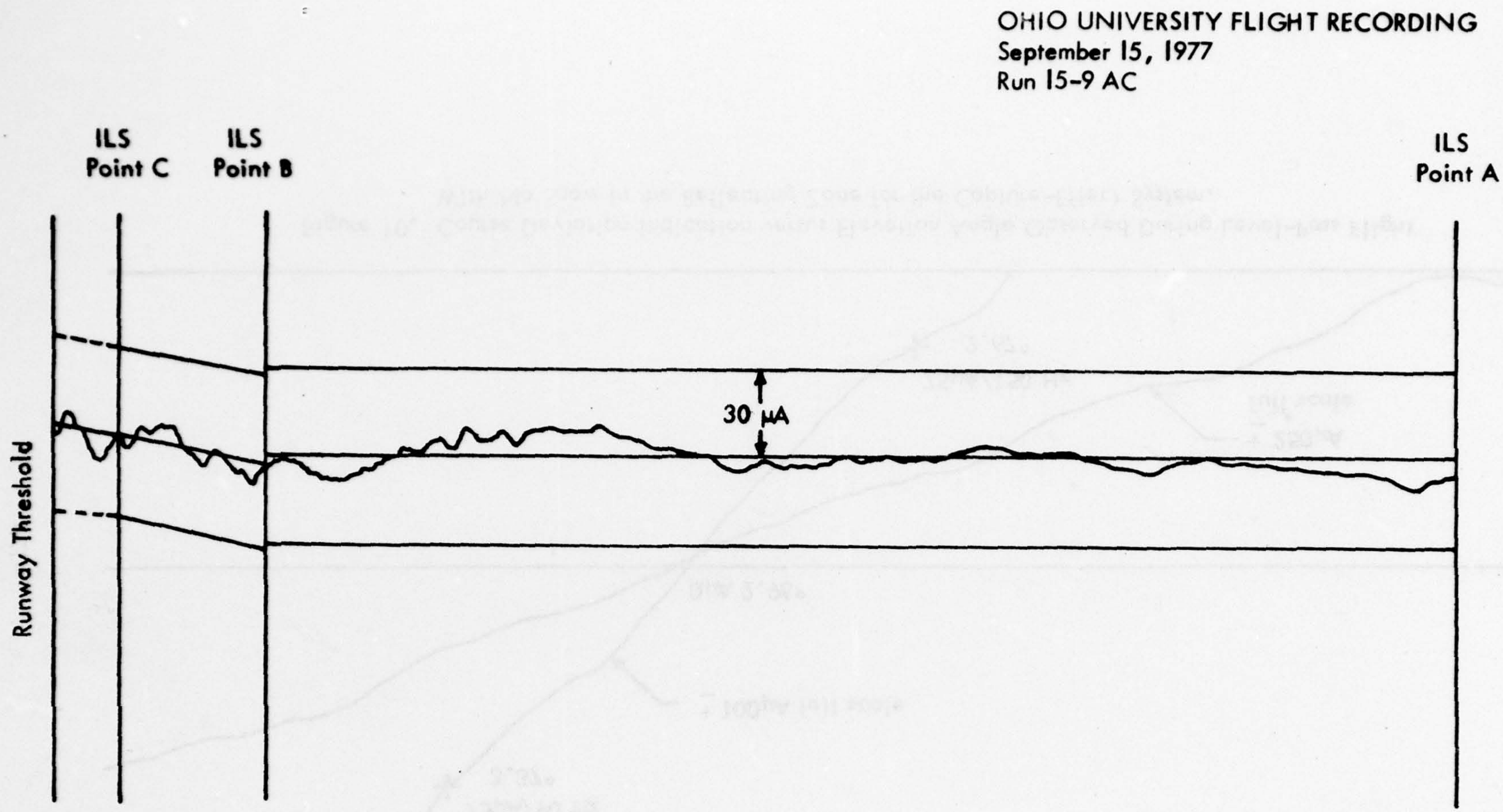


Figure 11. Deviation From 3° Path Angle versus Distance From Runway Threshold Observed During A Low-Approach Flight With No Snow in the Reflecting Zone for the Sideband-Reference System; Category II Tolerance Limits are Given.

OHIO UNIVERSITY FLIGHT RECORDING
September 14, 1977
Run 14-16 AC

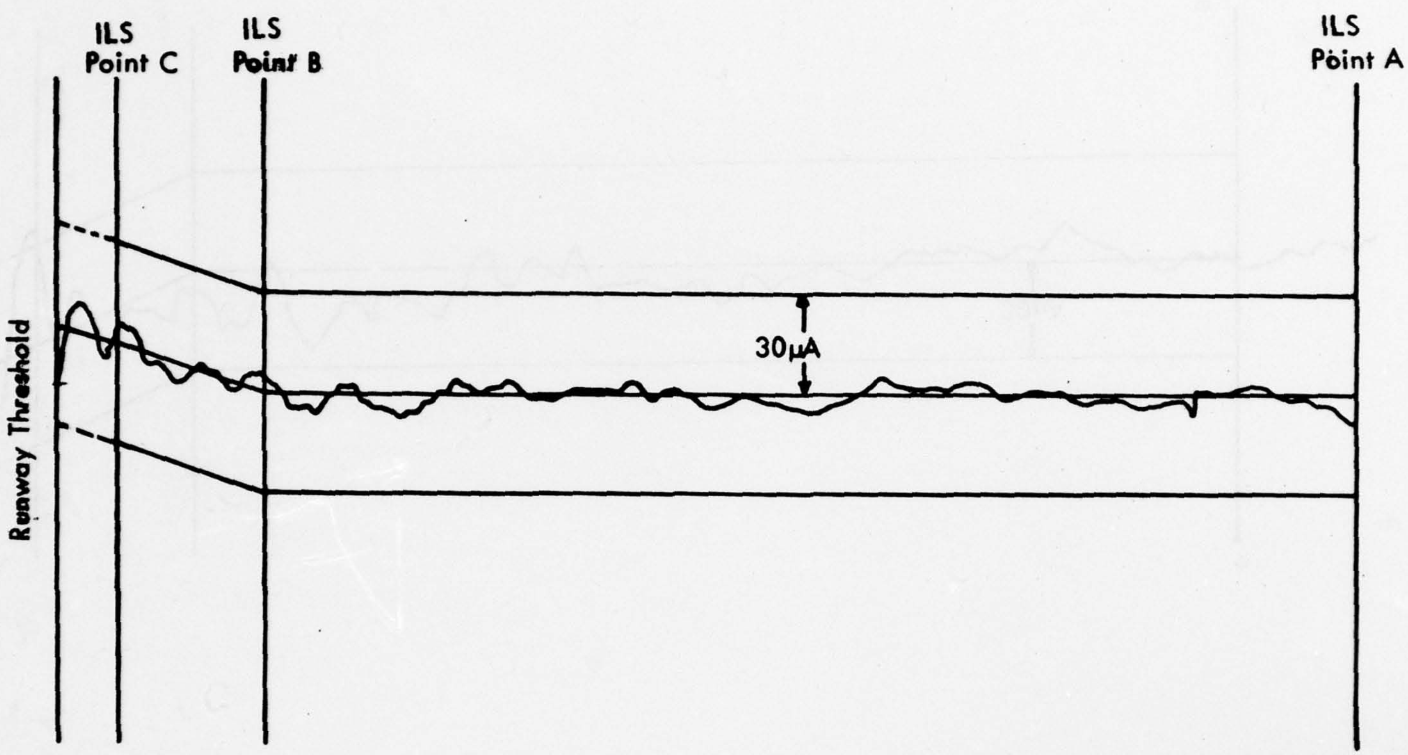


Figure 12. Deviation From 3° Path Angle versus Distance From Runway Threshold Observed During a Low-Approach Flight With No Snow in the Reflecting Zone for the Capture-Effect System; Category II Tolerance Limits are Given.

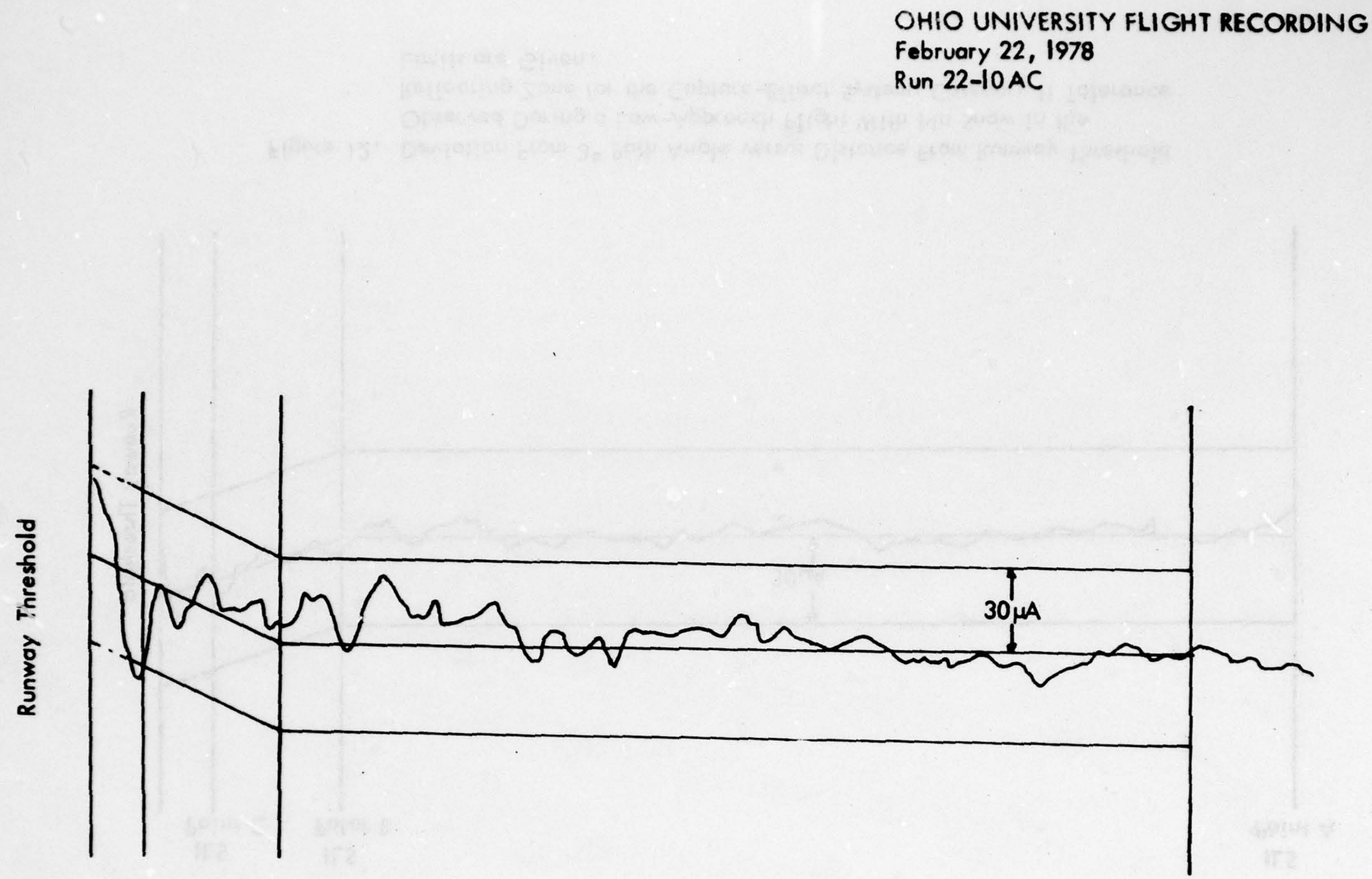


Figure 13. Deviation From 3° Path Angle versus Distance From Runway Threshold Observed During a Low-Approach Flight with 21 Inches of Snow in the Reflecting Zone for the Sideband-Reference System; Category II Tolerance Limits are Given.

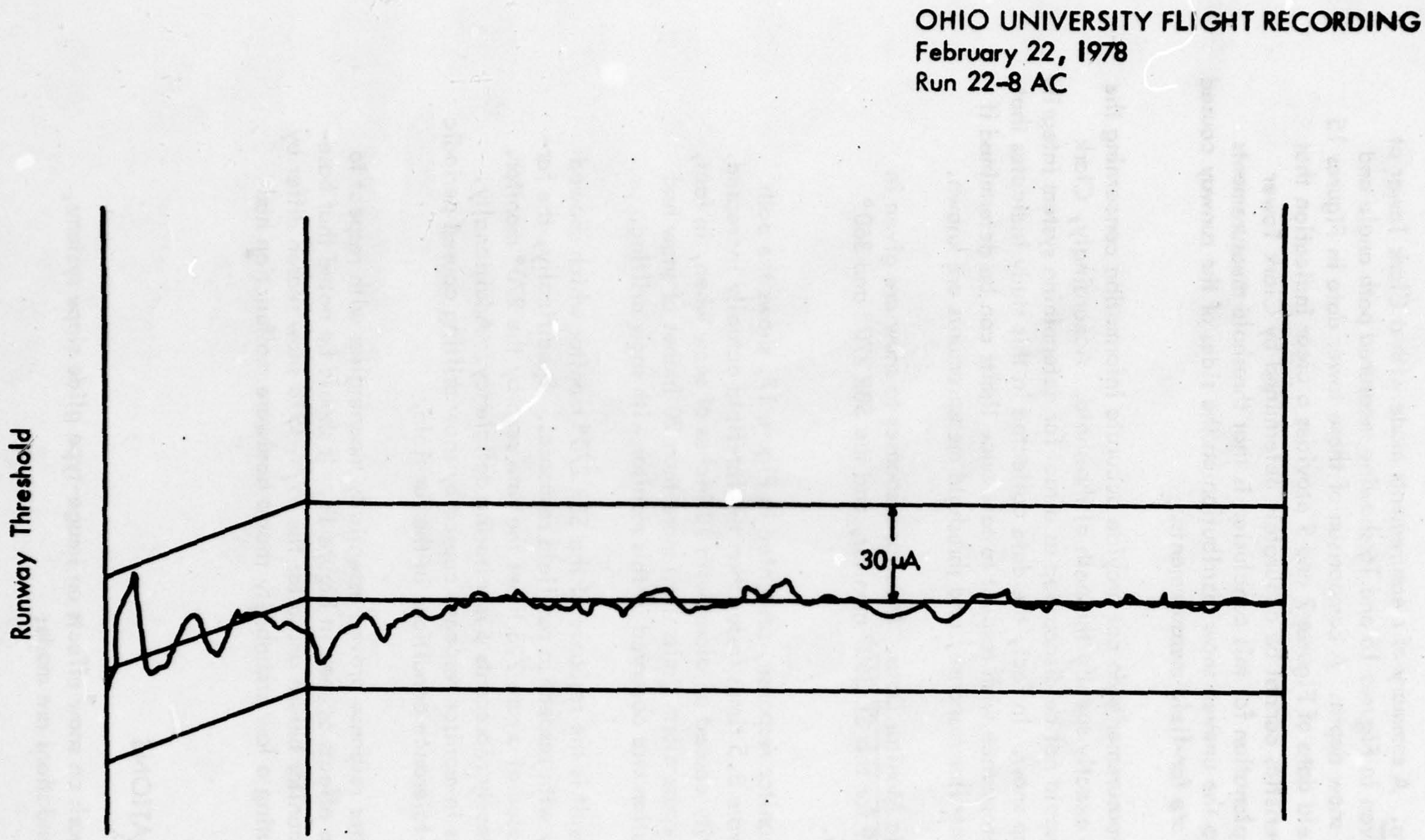


Figure 14. Deviation From 3° Path Angle versus Distance From Runway Threshold Observed During a Low-Approach Flight with 21 Inches of Snow in the Reflecting Zone for the Capture-Effect System; Category II Tolerance Limits are Given.

B. Tower Data. A summary of measurements made with a Clark Tower at runway threshold is given in Figures 15 and 16 showing measured path angle and width as a function of snow depth. A comparison of these tower data in Figures 15 and 16 with the far-field data of Figures 7 and 9 provides a clear indication that far-field path characteristics cannot be accurately determined by Clark Tower measurements. An explanation for this conclusion is that threshold measurements are more susceptible to the uneven snow distribution on the sides of the runway caused by snow removal than are far-field measurements.

Clark Tower measurements do not provide accurate information concerning the far-field path, but do exactly specify the path at threshold. Accordingly, Clark Tower measurements should not be discounted as a tool for determining system integrity in the presence of deep snow. In fact, the data collected in this study indicates that glide-slope system performance with respect to tolerance limits can be determined if snow depth, integral monitor response, and threshold measurements are known.

C. Near-Field Monitor Data. Monitor responses to snow are given in Figures 17, 18, and 19 for the CE 360° monitor, and the SBR 270° and 360° monitors, respectively.

The CE path monitor response, presented in Figure 17, shows the path angle increasing at a rate 3.5 times faster than the far-field actually increased. This increased sensitivity caused an alarm with 10 inches of snow when, in fact, the far field did not surpass alarm limits until more than 20 inches of snow had accumulated. Fluctuation was observed in this monitor with snow drifting.

A surprising result is the response of the SBR 270° monitor which showed a decreased sensitivity with respect to far-field responses. Specifically, the far-field path angle increased at a rate 2.3 times the rate seen by the 270° monitor. This desensitization clearly represents a monitoring deficiency. Additionally, substantial fluctuations in monitor response caused by snow drifting caused periodic alarms prior to out-of-tolerance conditions in the far field.

SBR 360° monitor response proved essentially meaningless with respect to any snow accumulation effects as seen in Figure 19. It should be noted that base-line readings for this monitor before and after the 1977-1978 snow season differ by only one DDM, indicating a low probability that a hardware malfunction had occurred.

VI. RECOMMENDATIONS

Based on the work on snow effects on image-type glide slope systems, the following recommendations are made:

1. The capability of predicting far-field path characteristics based upon snow depth and integral monitor readings should be further investigated.

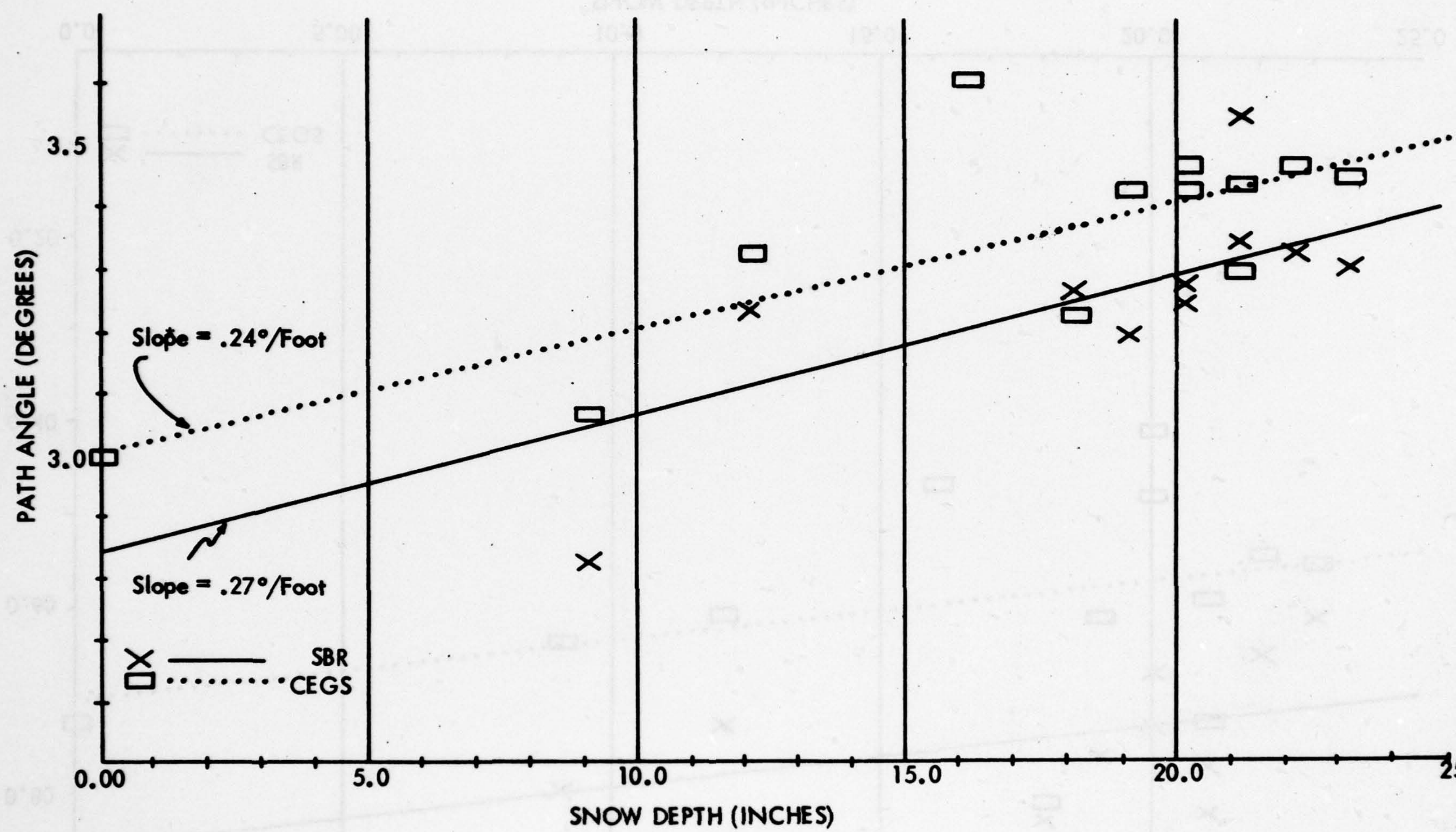


Figure 15. Path Angle Measured by the Telescoping Tower at Runway Threshold versus Snow Depth.

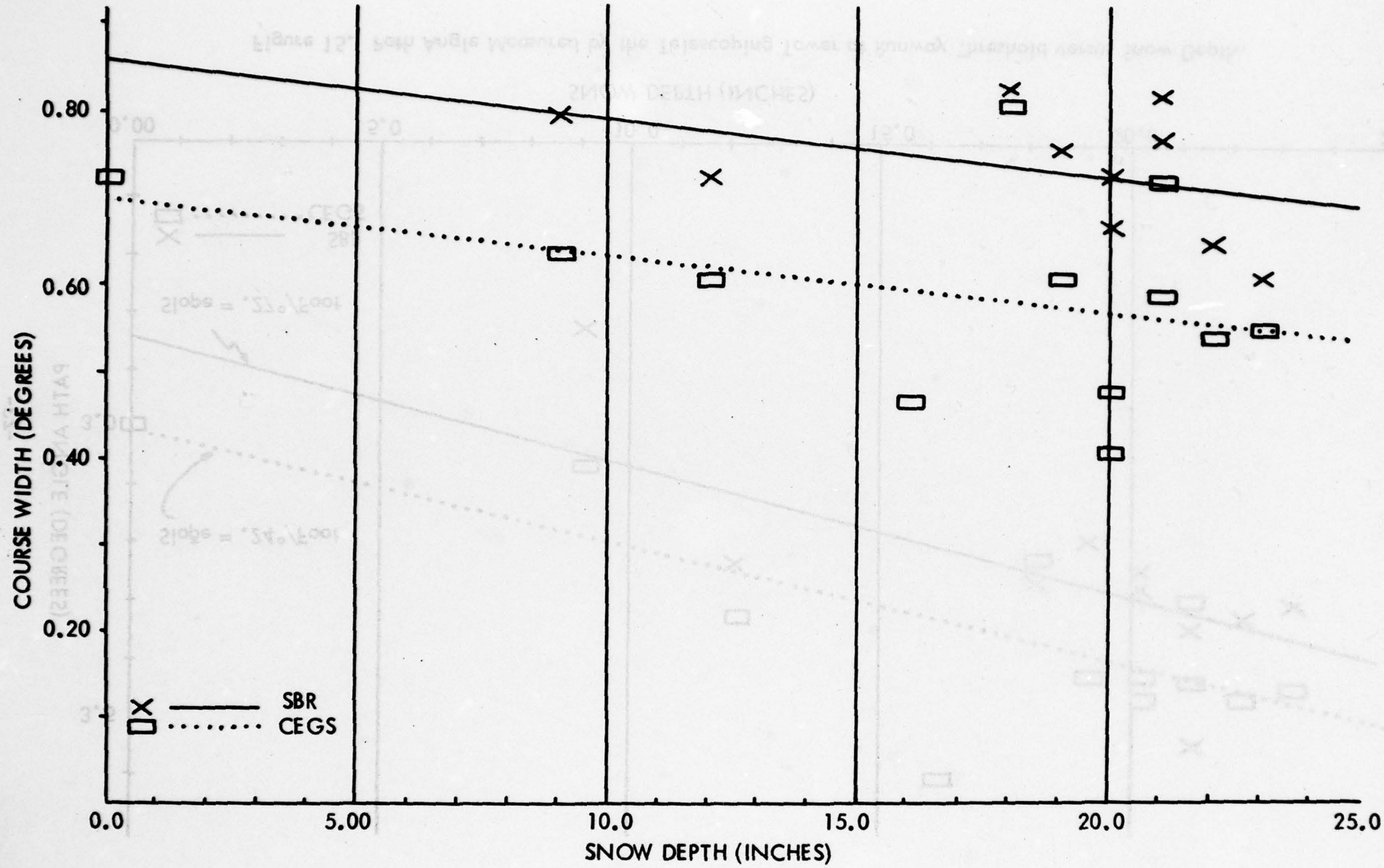


Figure 16. Path Width Measured by the Telescoping Tower at Runway Threshold versus Snow Depth.

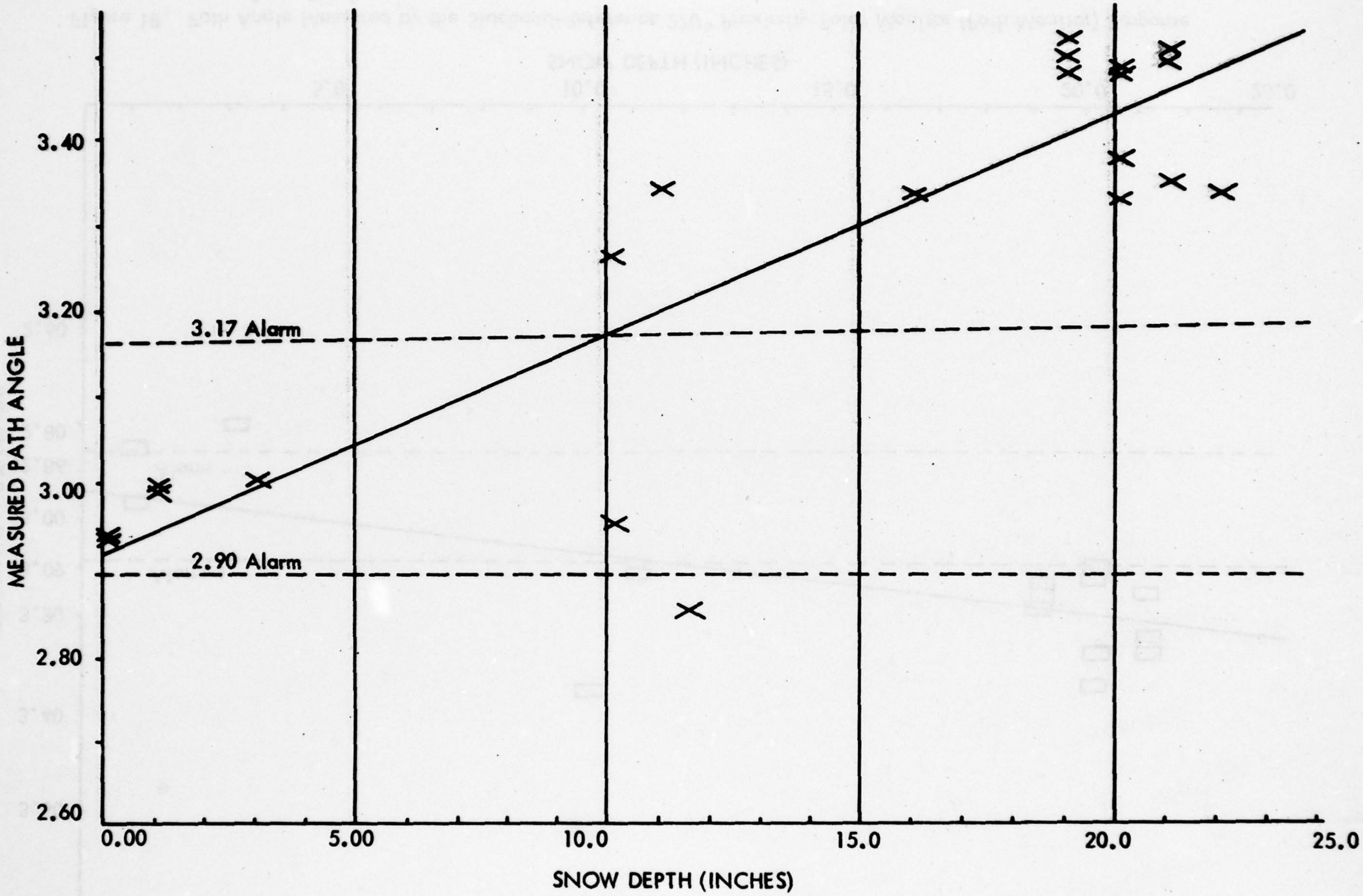


Figure 17. Capture-Effect 360° Proximity Point Monitor (Path Monitor) Response versus Snow Depth.

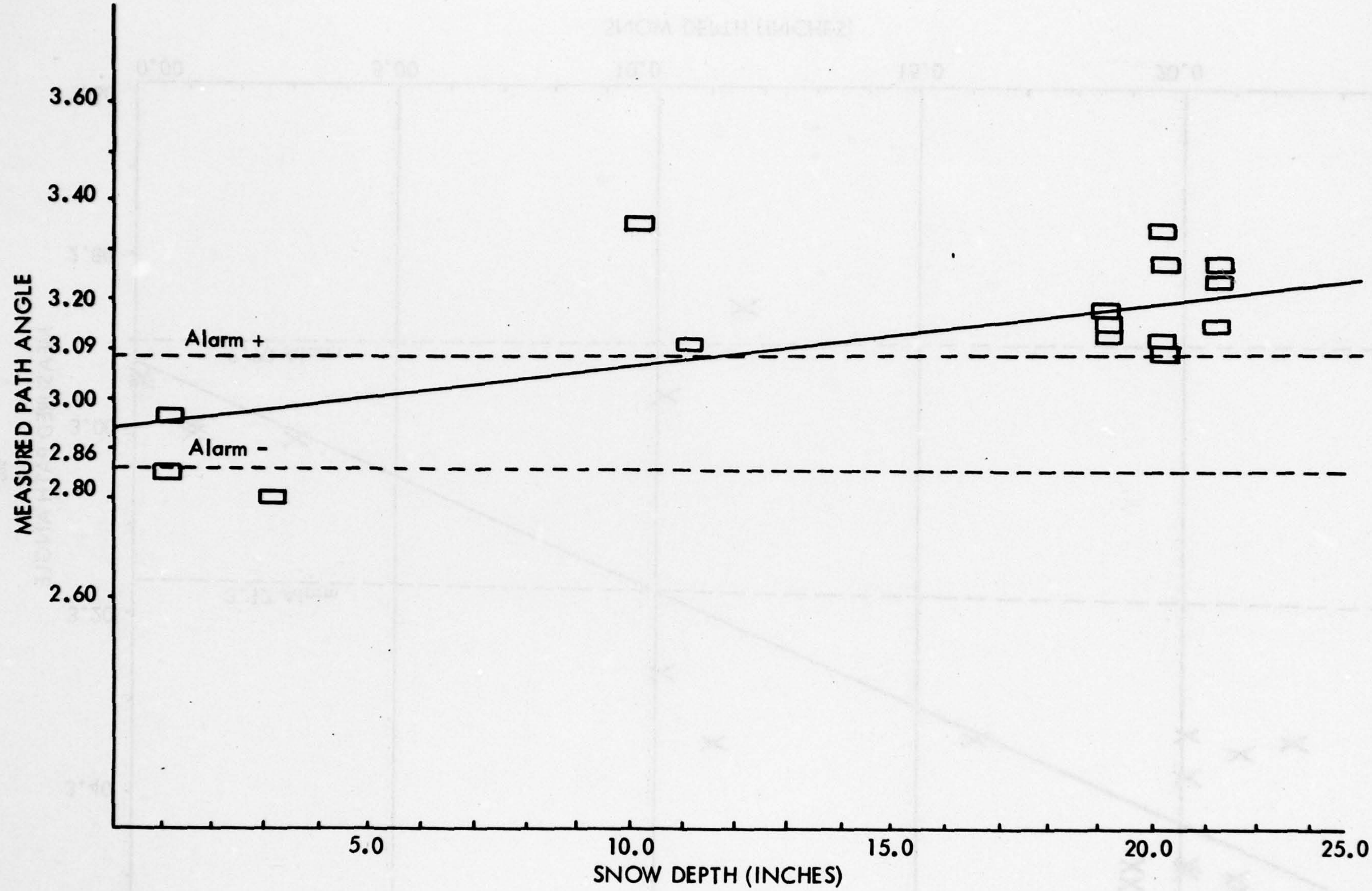


Figure 18. Path Angle Measured by the Sideband-Reference 270° Proximity Point Monitor (Path Monitor) Response versus Snow Depth.

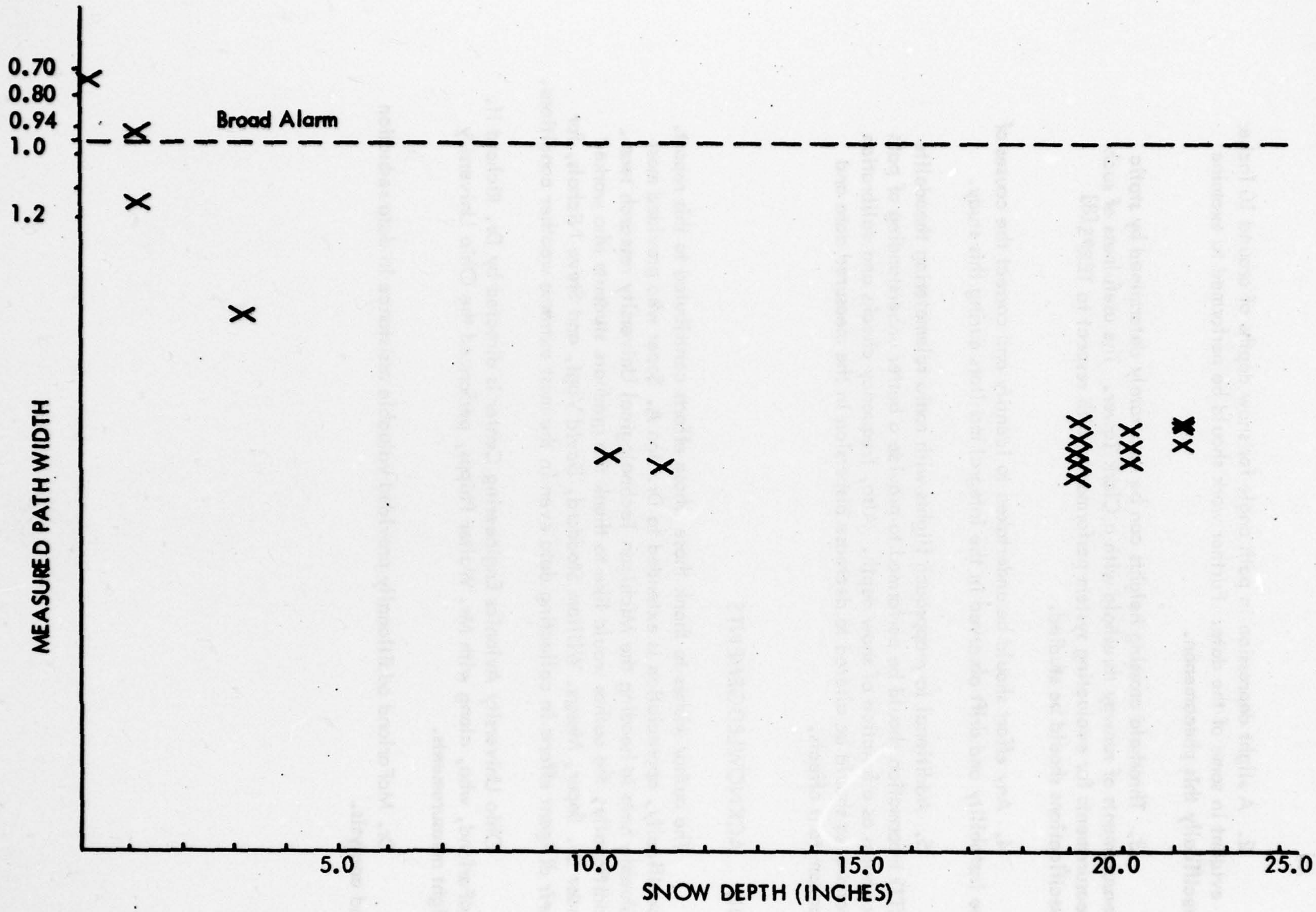


Figure 19. Path Width Measured by Sideband-Reference 360° Proximity Point Monitor (Width Monitor) Response versus Snow Depth.

2. A slight depression in path angle for snow depths of around 10 inches is evident in some of the data. Further work should be performed to examine specifically this phenomenon.

3. Threshold crossing heights can be accurately determined by static measurements of runway threshold with a Clark Tower. The usefulness of such measurements for evaluating system performance with respect to TERPS[8] specifications should be studied.

4. Any effort should be undertaken to identify and correct the causes of the instability and drift observed in the integral monitors during this study.

5. Additional low-approach flights with radio telemetering theodolite (RTT) information should be performed to provide a better understanding of path roughness as a function of snow depth. Also, frequency checks and calibration techniques should be altered to decrease dispersion in the measured data and concomitant affects.

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Dr. McFarland additionally provided valuable assistance in data reduction and analysis.

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